

Chemistry-Climate Observations and CMIP6 Model Evaluation Needs

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IGAC/SPARC Chemistry-Climate Modeling Initiative (CCMI)

IGAC = International Global Atmospheric Chemistry

SPARC = Stratosphere (now “-Troposphere”, silent “T”) Processes and their Role in Climate

→ What is CCMI?

1) supersedes SPARC CCMVal (Chemistry-Climate Model Validation),
expanding evaluation activities to include tropospheric processes

identifying & compiling satellite, aircraft, & in situ datasets now

2) performing sensitivity simulations (hindcast/forecast)

Ref-C1 (1960-2010) & Ref-C1-SD (1980-2010) - [NASA GEOS-5 CCM]

initial evaluations underway

→ What are the relevant science needs from the chemistry-climate perspective? *(Answer: Depends on who you ask!)*

“Grand Challenge” = OH

+ several others *(e.g., ozone trends)*

Why OH?

- primary atmospheric oxidant
- controls lifetimes of some GHGs, like methane & HFCs
- important player in tropospheric ozone, another GHG

Why does OH = “Grand Challenge”?

- very, very few direct observations of OH to constrain model OH
- OH has short-lifetime (< 1 s), so much spatiotemporal variation
- many factors influence OH (e.g., CO, CH₄, water vapor, overhead ozone column, NO_x, clouds, aerosols, etc.)**

****An evaluation of OH requires an evaluation of many trace gases, aerosols, and clouds, all of which are important to climate directly or indirectly.**

What do MIPs tell us about model OH?

ACCMIP = Atmospheric Chemistry-Climate Model Intercomparison Project

Table 1. Present day (2000) tropospheric mean (air mass weighted) OH concentration, tropospheric chemical methane lifetime (τ_{OH}), and total methane lifetime (τ) for the 14 participating models. Multi-model means and standard deviations, as well as mean OH concentrations under different tropopause definitions, are also shown. If not indicated otherwise, we integrated the tropospheric OH loss from 200 hPa to the surface. The last row shows the means and standard deviations using a subset of models, excluding HadGEM2 and UM-CAM.

Models	Mean OH ($10^5 \text{ molec. cm}^{-3}$)	$\tau_{\text{OH}}(\text{chemical})$ (yr)	$\tau(\text{total})$ (yr) ^a
CESM-CAM-superfast	12.9	8.4	7.5
CICERO-OsloCTM2	10.4	10.0	8.7
CMAM	10.8	9.5	8.3
EMAC	11.8	9.2	8.1
GEOSCCM	11.4	9.7	8.5
GFDL-AM3	11.7	9.4	8.3
GISS-E2-R	10.6	10.6	9.2
HadGEM2	8.1	11.4	8.8
LMDzORINCA	10.3	10.4	9.1
MIROC-CHEM	12.5	8.8	7.8
MOCAGE	13.4	7.1	6.4
NCAR-CAM3.5	12.1	9.3	8.5
STOC-HadAM3	12.2	9.0	8.0
UM-CAM	6.5	13.9	11.6
Mean \pm stand. dev.	11.1 ± 1.8	9.8 ± 1.6	8.6 ± 1.2
Mean \pm stand. dev. (with trop1 ^b)	11.1 ± 1.7	9.7 ± 1.6	—
Mean \pm stand. dev. (with trop2 ^c)	11.0 ± 1.8	9.8 ± 1.6	—
Mean \pm stand. dev. (selected models)	11.7 ± 1.0	9.3 ± 0.9	8.2 ± 0.8

τ_{CH_4} w.r.t.
tropospheric
OH

^a For the total lifetime, we add to the tropospheric chemical loss a 30 Tg yr^{-1} methane sink in soils and a 40 Tg yr^{-1} sink to the stratosphere (Stevenson et al., 2006).

^b For trop1, we integrated the tropospheric OH loss from the $\text{O}_3 = 150 \text{ ppbv}$ surface to the Earth's surface, e.g. Stevenson et al. (2006).

^c For trop2, we integrated the tropospheric OH loss from the surface defined by $300-215 \times \cos(\text{lat})^2 \text{ hPa}$ to the Earth's surface, e.g. Shindell et al. (2006b).

What do MIPs tell us about model OH?

PolMIP = Polar Model Intercomparison Project

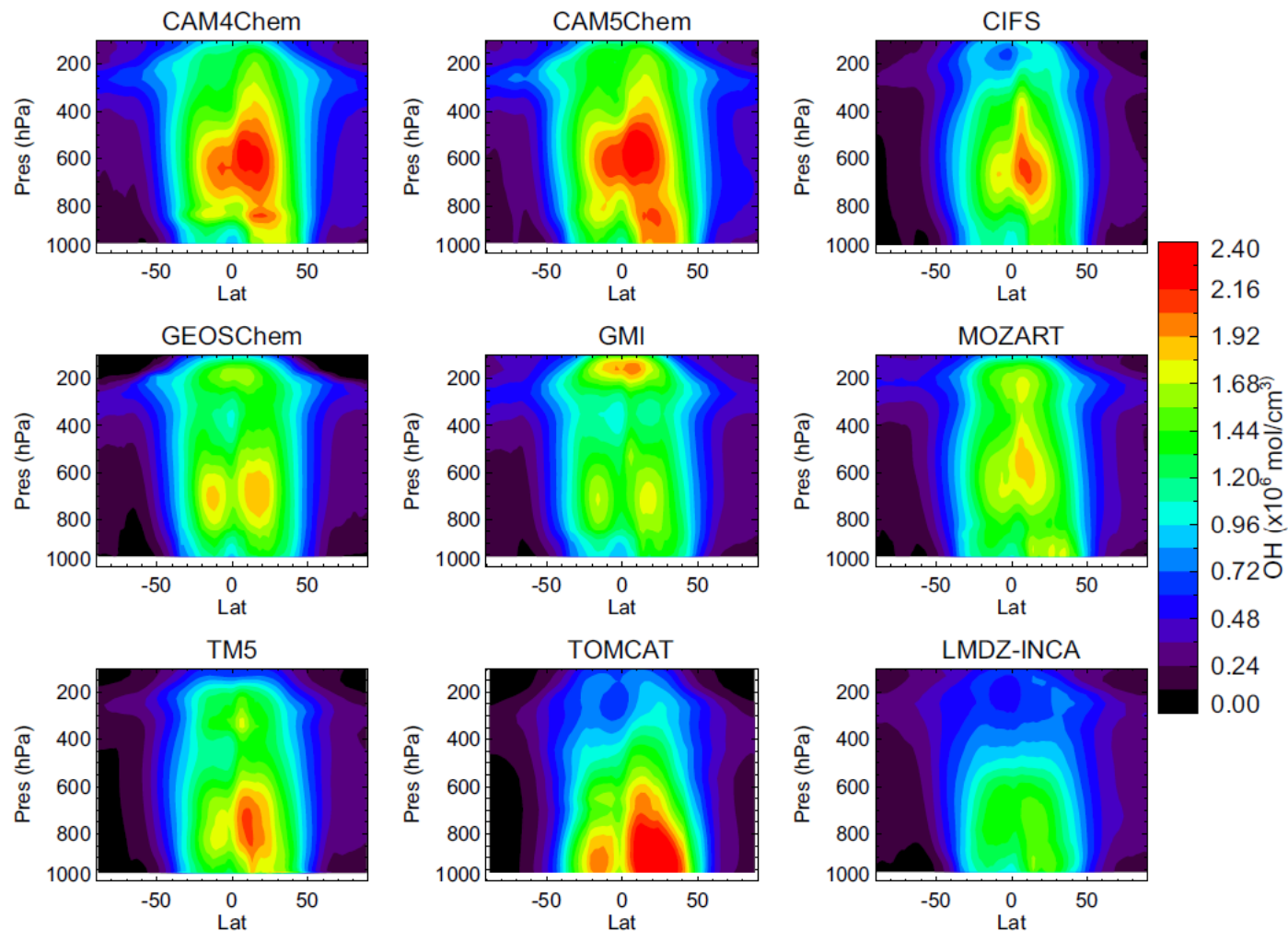
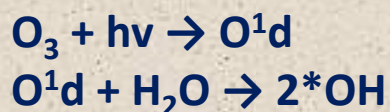


Fig. 11. Annual zonal mean OH concentrations ($\times 10^6 \text{ molecules/cm}^3$) for 2008 from the POLMIP models.

Monks et al., ACPD, 2014

Data Needs for Evaluating OH

Primary Production



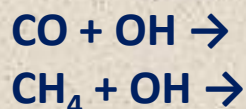
NEED: ozone column, clouds, aerosols, ozone, H_2O

Secondary Production



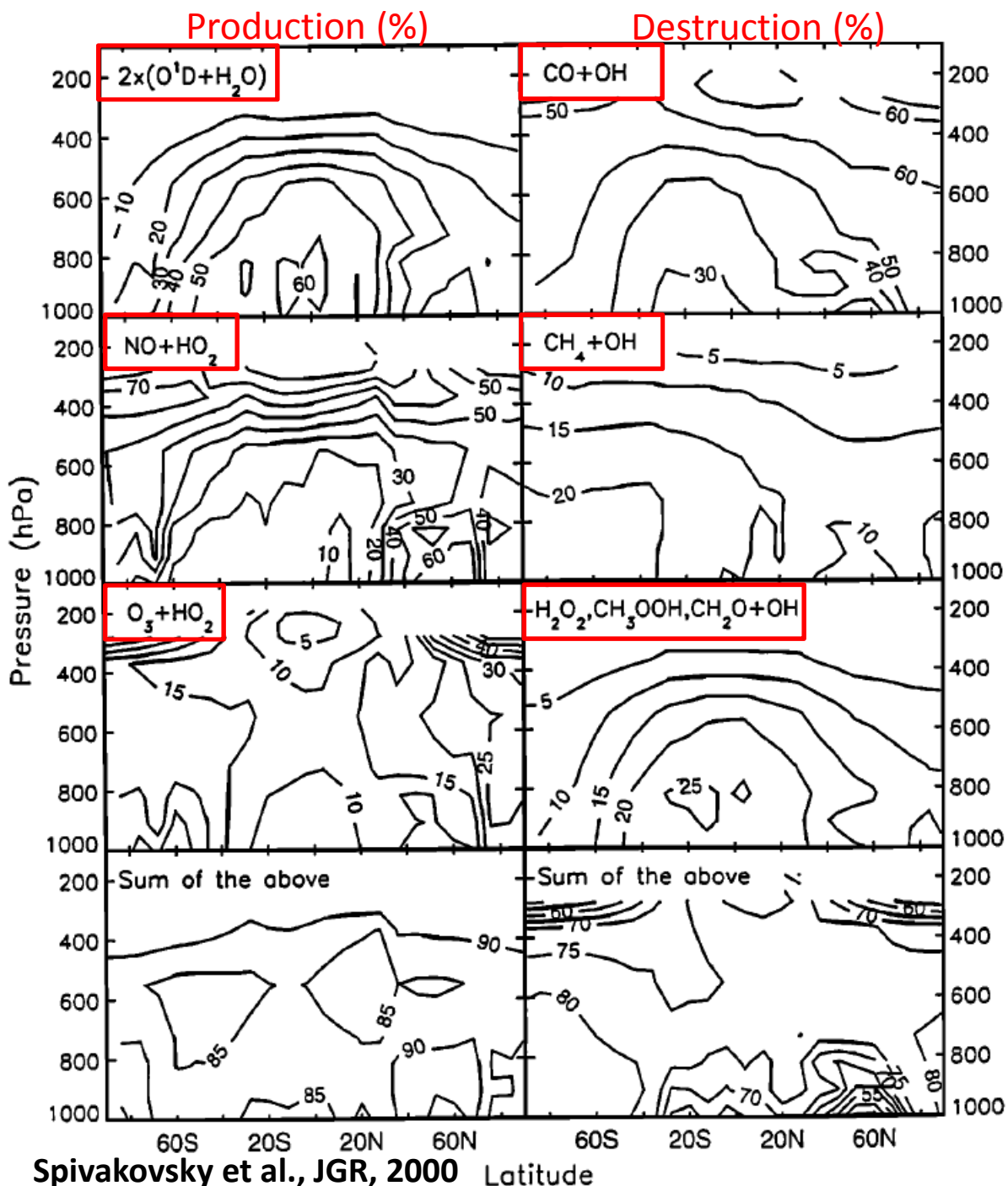
NEED: NO_2 (lightning flashrates)

Primary Destruction



NEED: CO , CH_4

SPIVAKOVSKY ET AL.: CLIMATOLOGICAL DISTRIBUTION OF TROPOSPHERIC OH



Data Needs for Evaluating OH

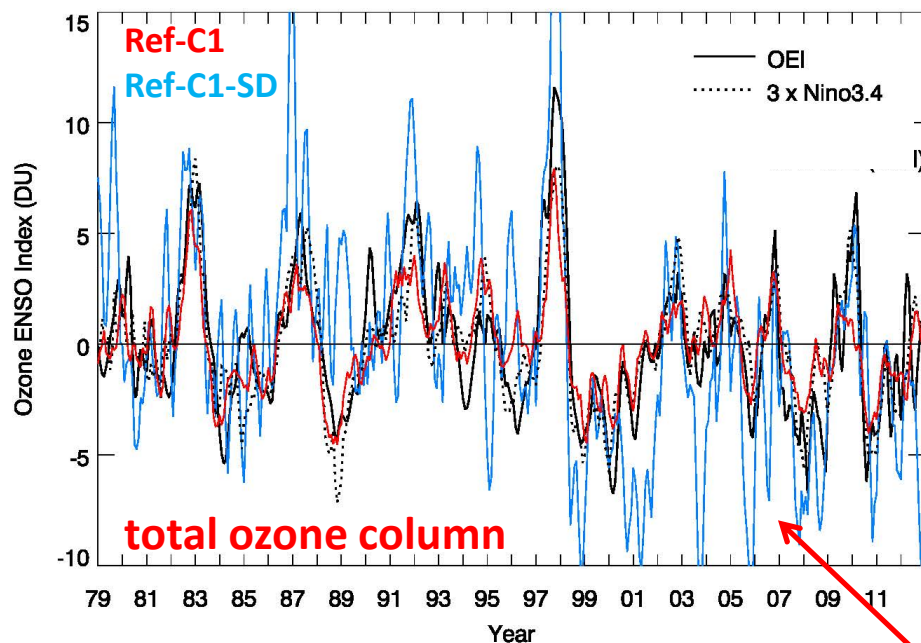
Data to constrain the processes that influence OH as well as all other gases

- ENSO (*satellite*)
- Stratosphere-troposphere exchange (*aircraft, ozonesondes*)
- Clouds, clouds, clouds (*Can CCMI benefit from CMIP5 effort?*)
- Others to tackle?

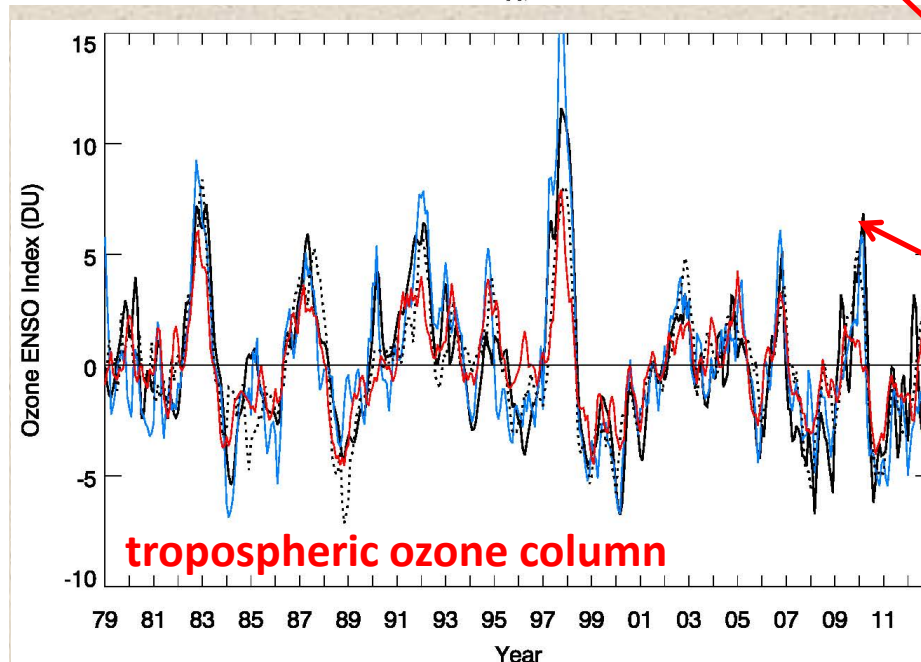
→ Obs4MIPs:

- 1) need data to constrain distributions & processes that influence OH*
- 2) need data uncertainties (“unknowable”?) to be clearly documented*
- 3) need clear, user-friendly data documentation (e.g., AK’s)*

Data to Constrain Processes that Influence OH: *ENSO*



CCM (GCM w/observed SSTs) = Ref-C1
CTM (MERRA reanalysis fields) = Ref-C1-SD



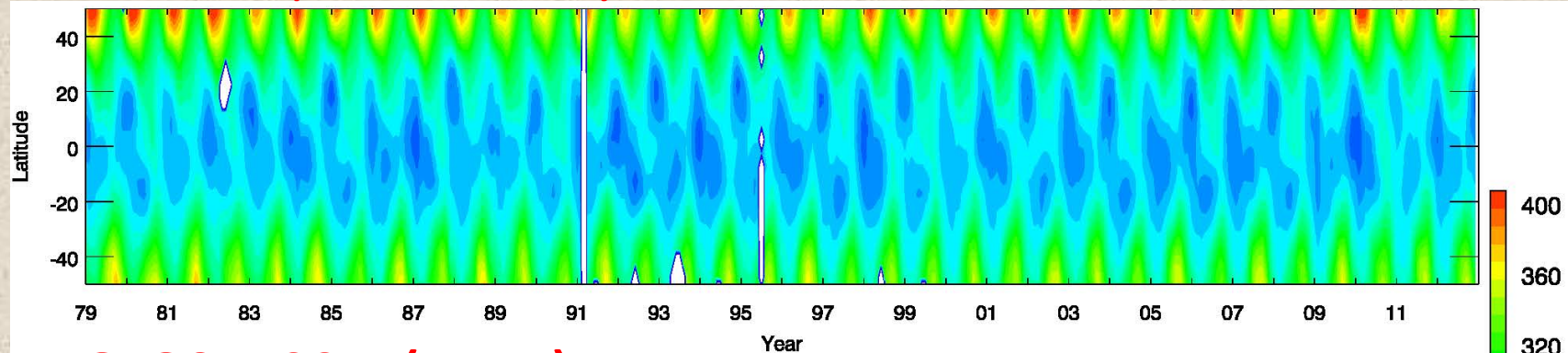
CTM simulation has issues in the stratosphere, which has implications for OH!

Tropospheric portion looks great.

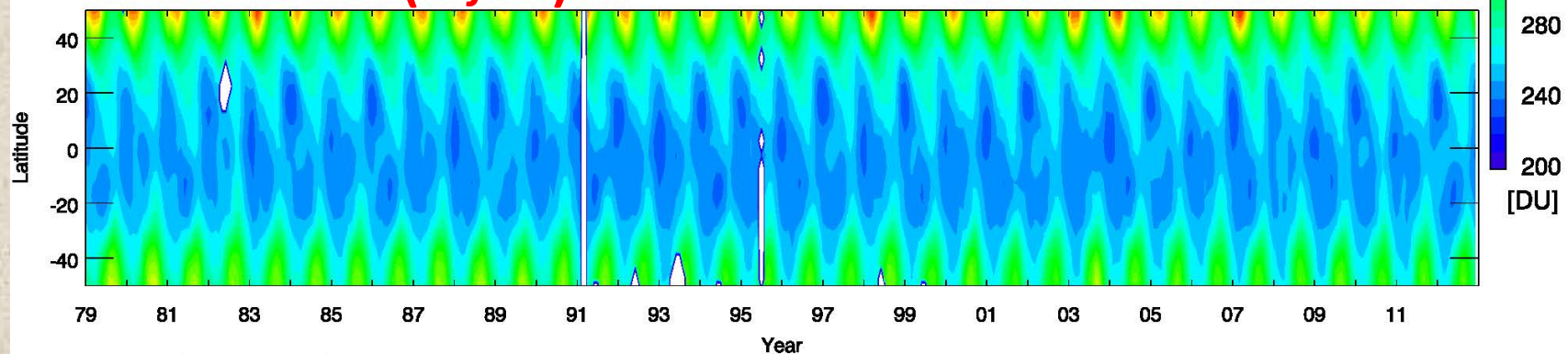
Ziemke et al., JGR, 2010

Data to Constrain Processes that Influence OH: O_3 Column

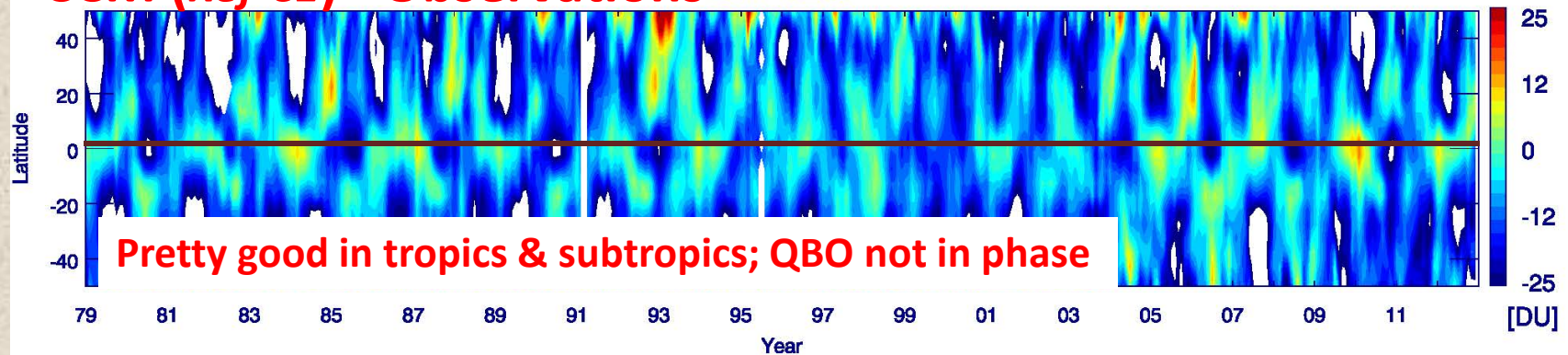
SBUV v8.6 (*Frith et al., 2014*)



GEOS-5 CCM (*Ref-C1*)



CCM (*Ref-C1*) - Observations

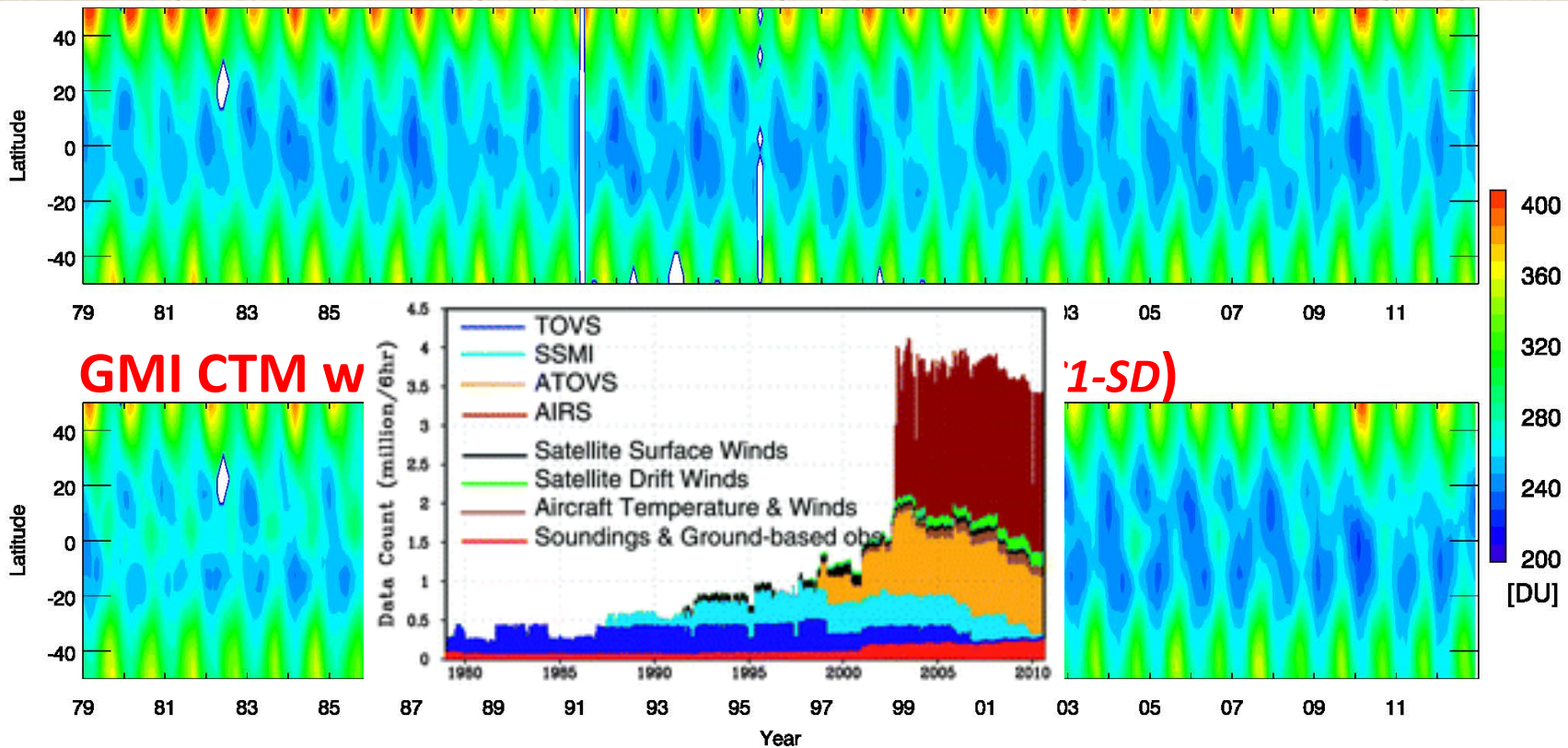


~ +5 to -10% in tropics

Pretty good in tropics & subtropics; QBO not in phase

Data to Constrain Processes that Influence OH: O_3 Column

SBUV v8.6

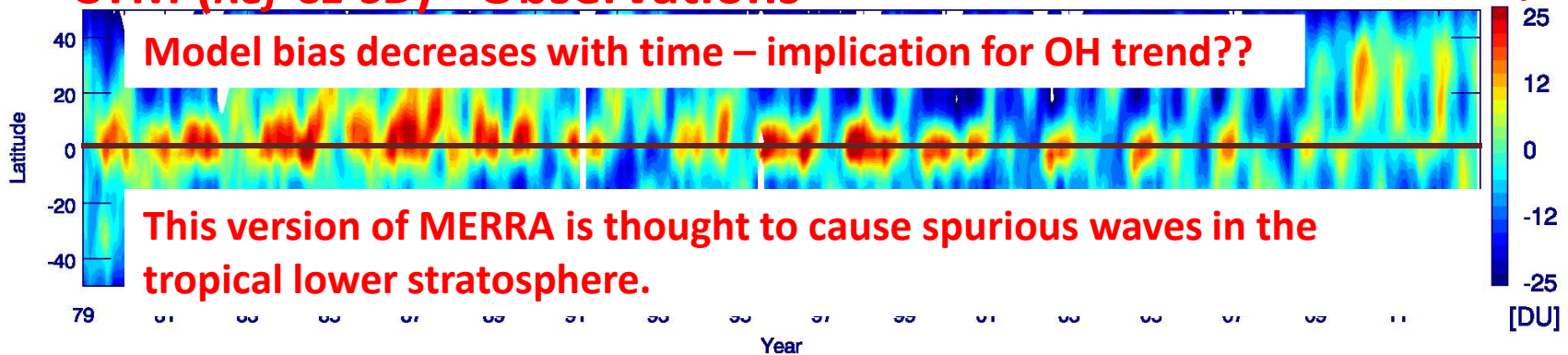


CTM (*Ref-C1-SD*) - Observations

~ +0-10% in tropics

Model bias decreases with time – implication for OH trend??

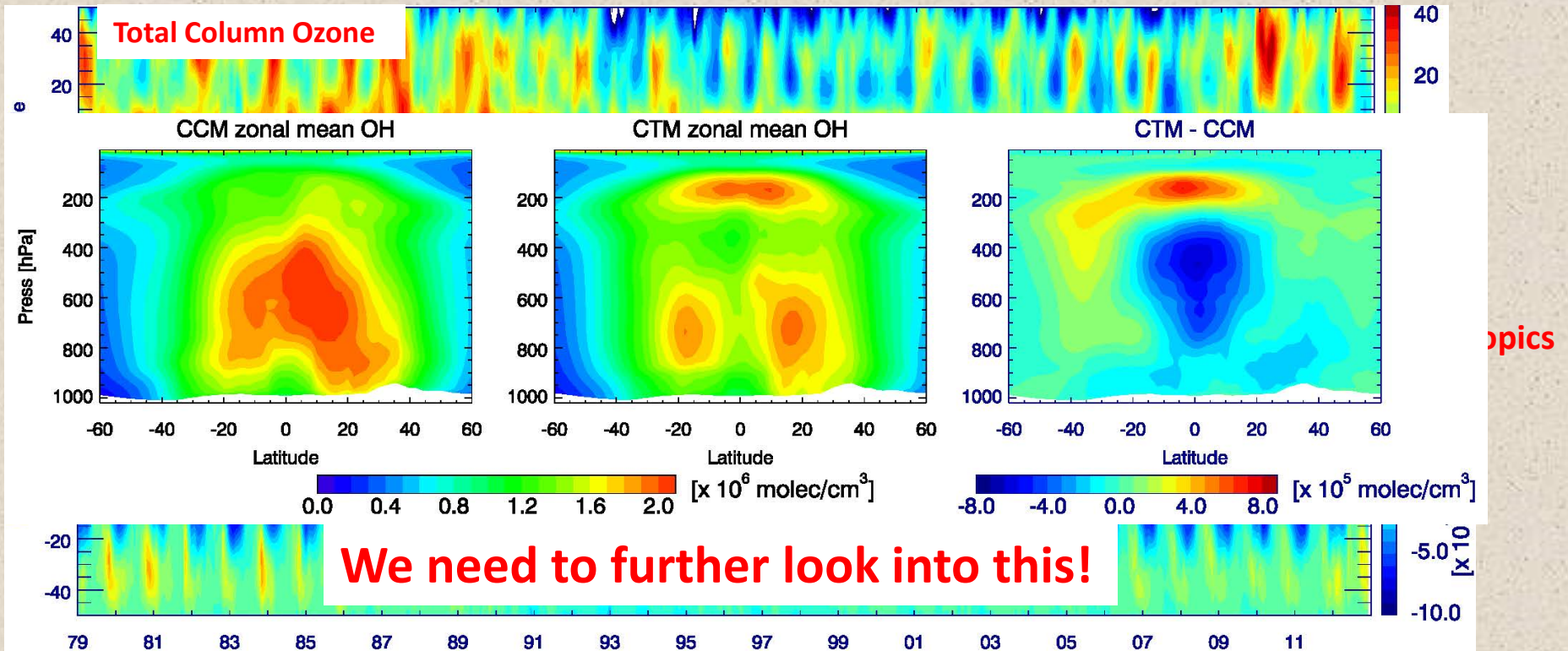
This version of MERRA is thought to cause spurious waves in the tropical lower stratosphere.



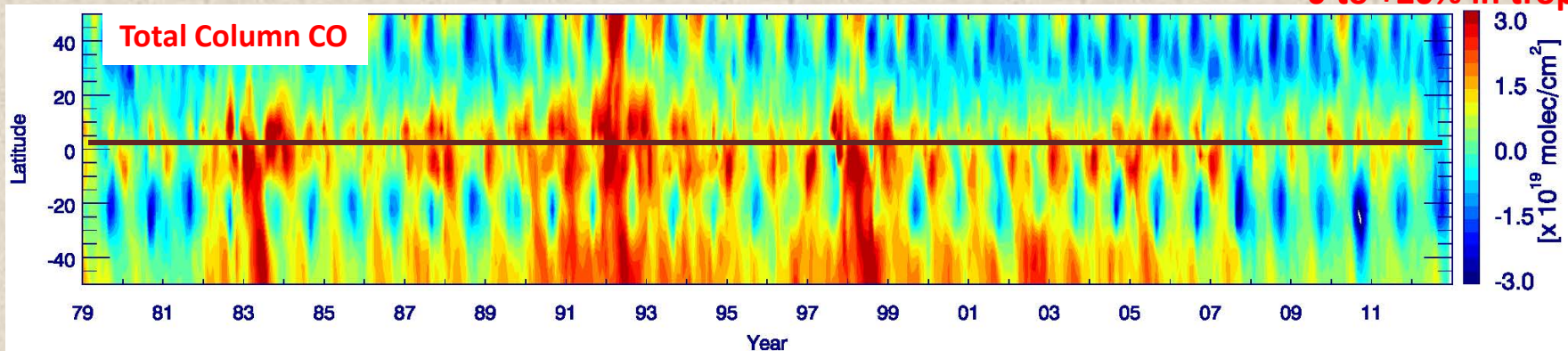
Data to Constrain Processes that Influence OH: O_3 Column

CTM (Ref-C1-SD) – CCM (Ref-C1)

~0-12% in tropics



~0 to +20% in tropics

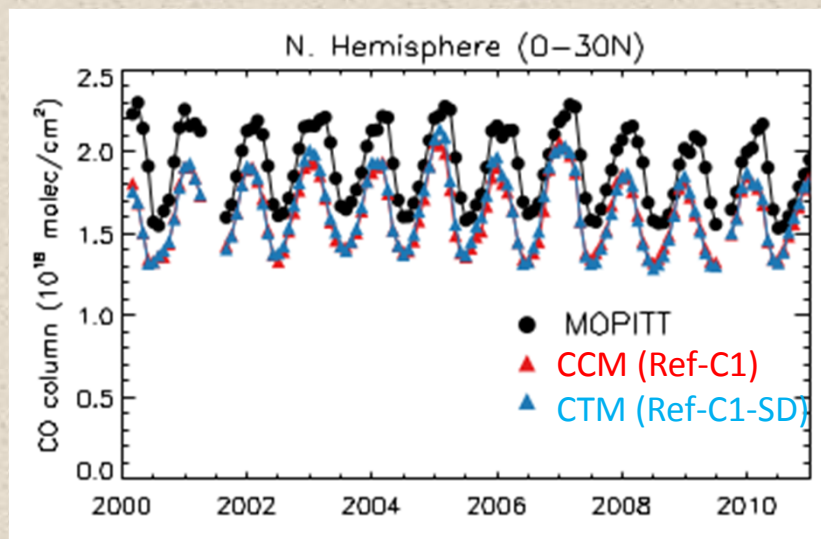


How can the CCMI-effort contribute to Obs4MIPs?

→ Provide guidance on desired datasets & contribute satellite, aircraft, ozonesonde & surface datasets.

→ Help to make documentation user-friendly:

Discuss strengths & limitations, uncertainty estimates, how to apply AK's, etc.



Oftentimes the differences between sensitivity simulations are less than between simulations & data!

1) Satellite data uncertainties are often poorly quantified or “unknowable”. Biases vs. in situ observations difficult.

[e.g., EU FP7 project 'Quality Assurance for multi-decadal ECVs' (QA4ECV) – satellite variables of climate]

2) Is model CO too low (e.g., too low emissions) so OH is too high? Or is model OH too high for another reason which causes CO to be too low? Our CCMI evaluations require us to look at the suite of factors that influence OH!

Initial Diagnostics/Satellite Datasets

1) Ozone: OMI, MLS, TES

- a) OMI/MLS Ozone ENSO Index (OEI)*
- b) MLS/TES diagnostic of ozone response to ENSO*

2) H₂O_v: AIRS, MLS

- a) Vertical distribution – assess bias*
- b) Variation of H₂O_v with ENSO*
- c) Seasonal variation*

3) Clouds: SBUV, SBUV/2 - LER product; MODIS - MOD08 product

- a) Variation of clouds with ENSO*
- b) Seasonal variation*

4) Overhead Ozone Column: TOMS, OMI

5) NO₂: OMI – limited!

6) CO: MOPITT v6

- a) Seasonal variation*

7) Methane: SCIAMACHY – limited!

- a) Inter-hemispheric gradient*

8) Lightning: OTD/LIS

- a) Variation of lightning with ENSO*
- b) Seasonal variation*

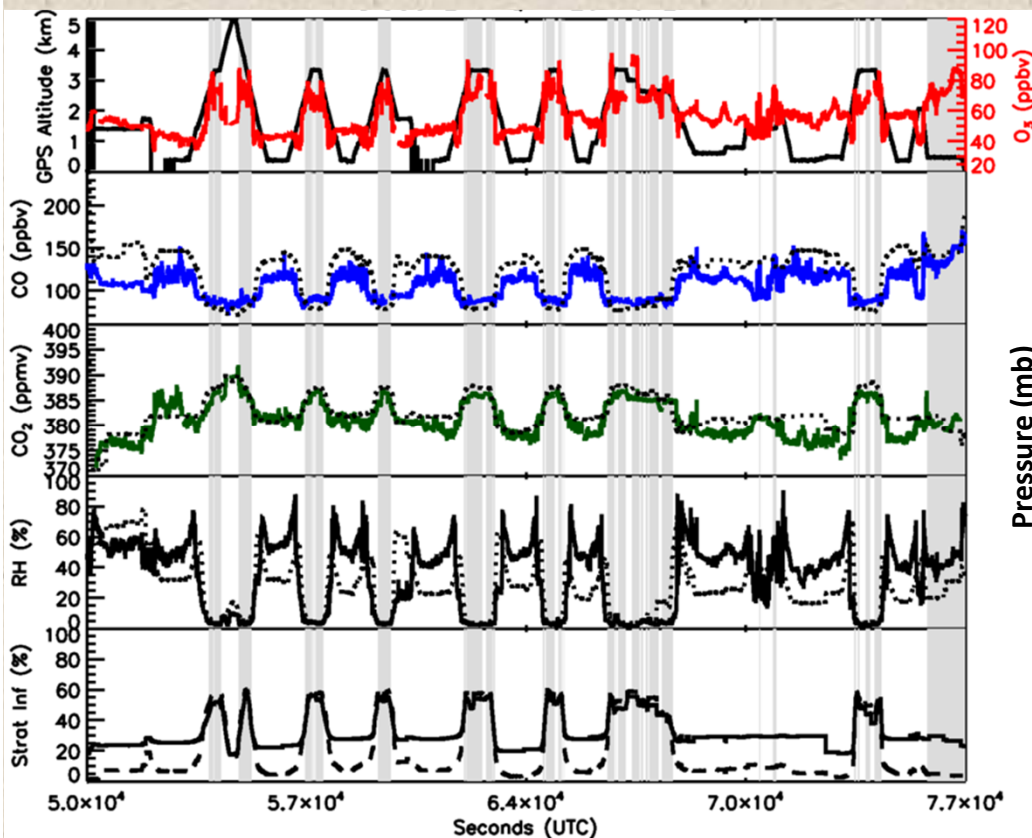
Backup Slides

Data to Constrain Processes that Influence OH: *STE*

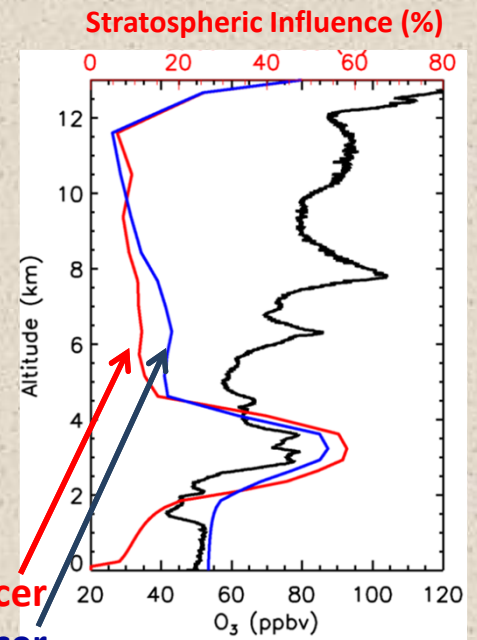
→ Satellite data limited for assessing the impact of intrusions on H_2O_v , CH_4 , CO , O_3 , etc., which impact OH & net O_3 P.

DISCOVER-AQ Field Campaign: July 2011 Maryland

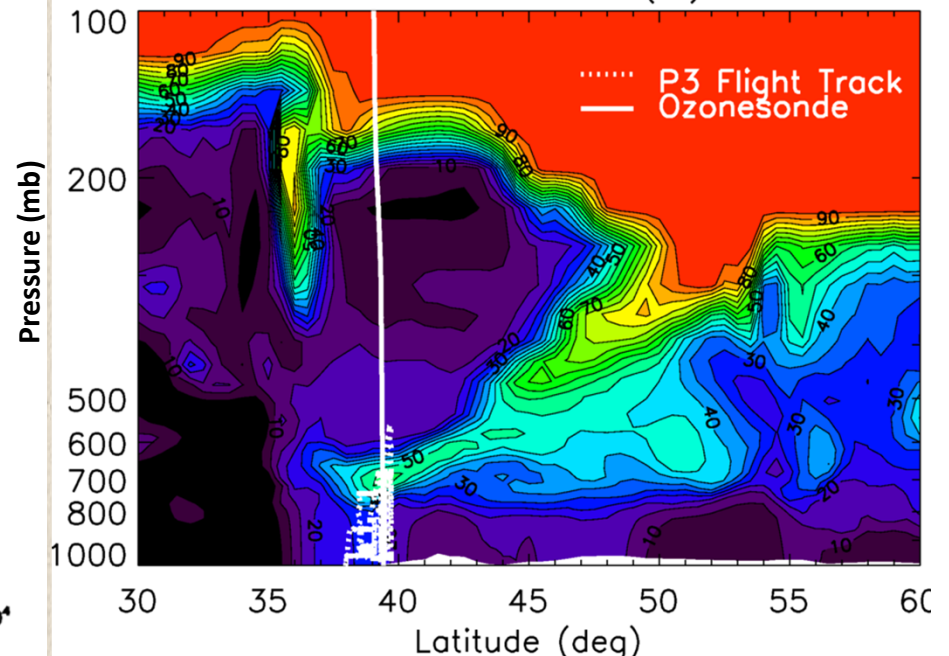
- July 27th: a deep stratospheric intrusion
- Several deep intrusions encountered by aircraft in July



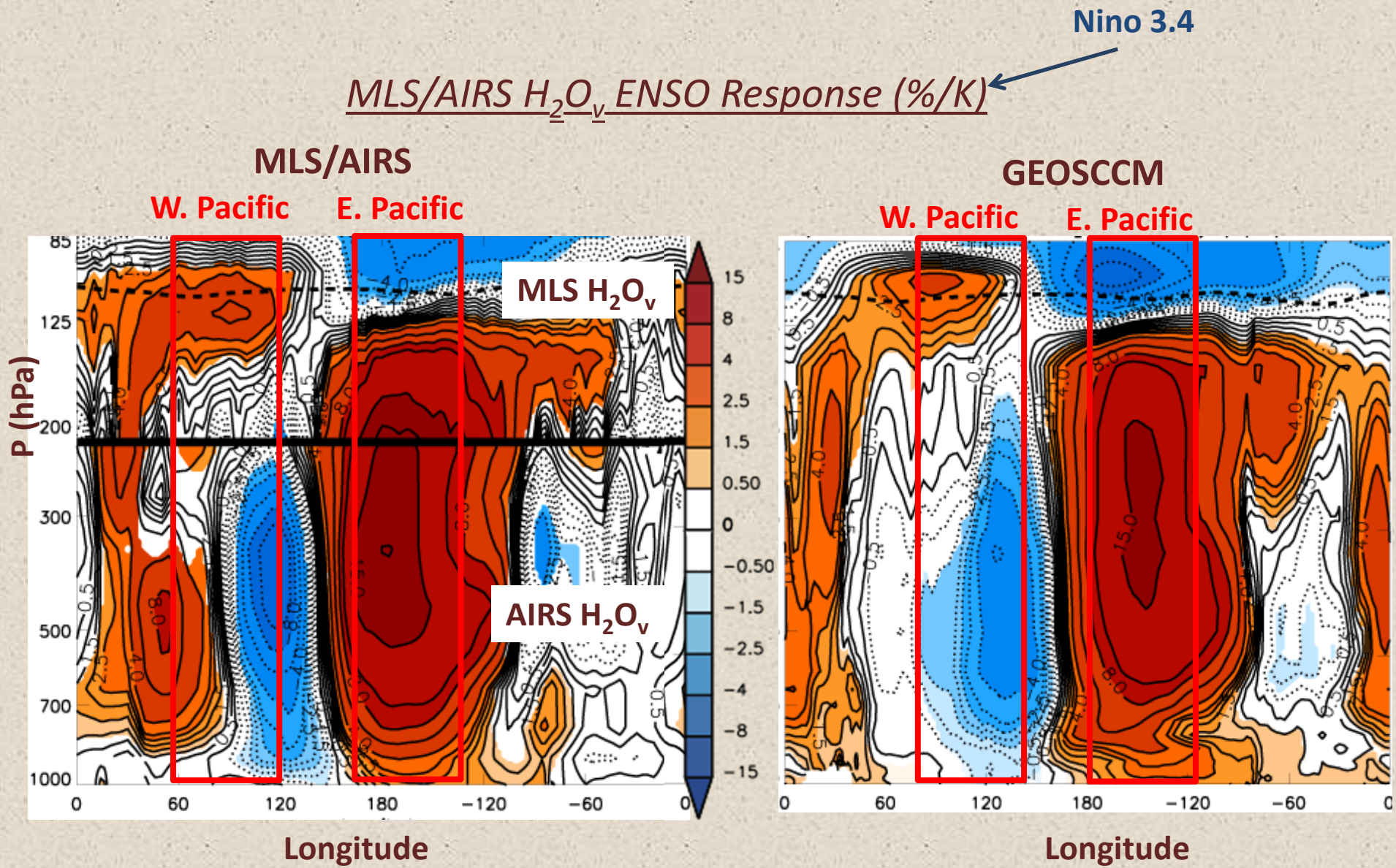
“Surface Loss” Tracer
“Pulse” Tracer



GEOS-5 Strat Influence (%) – 76.5°W

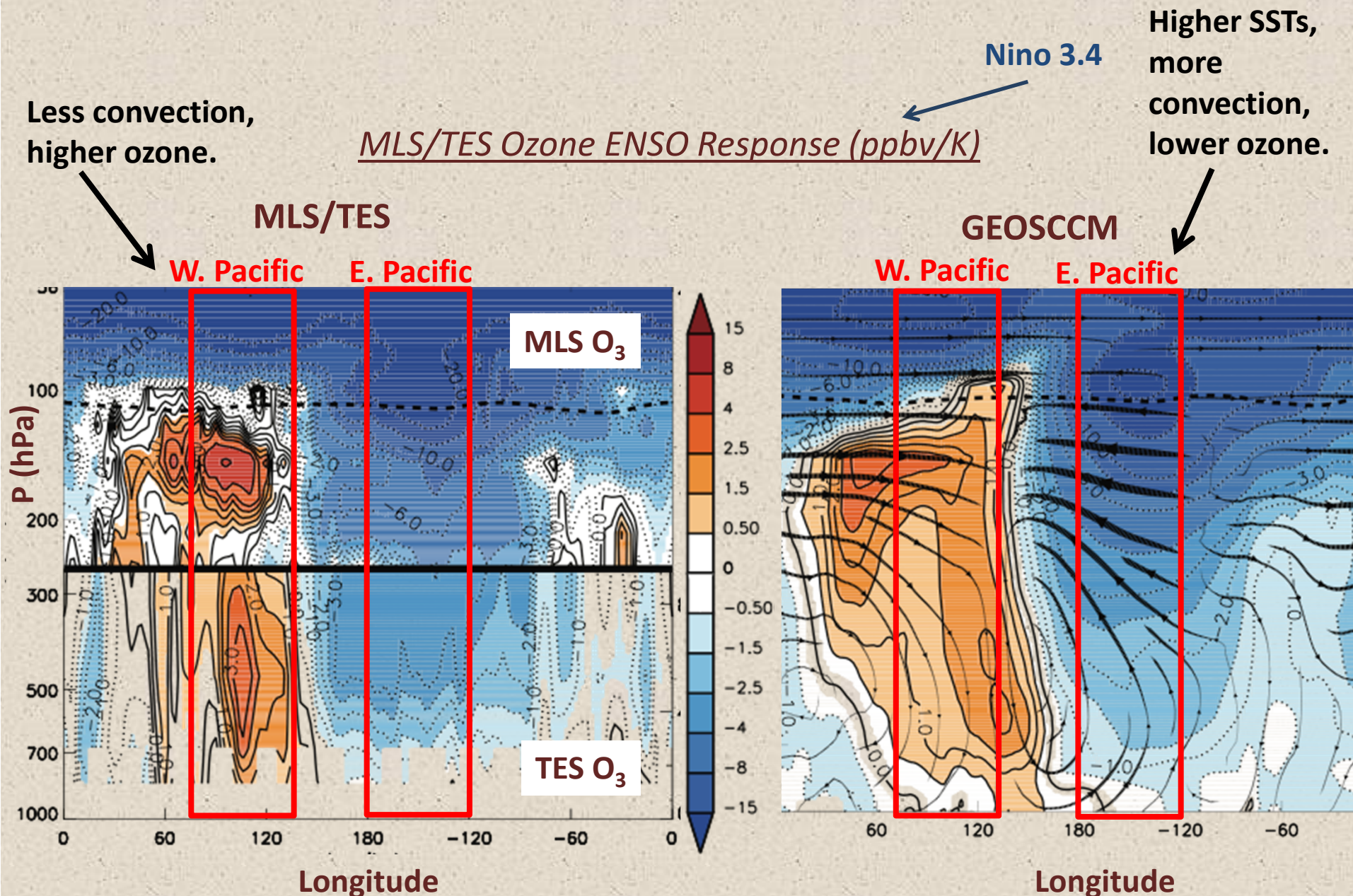


Data to Constrain Processes that Influence OH: *ENSO*



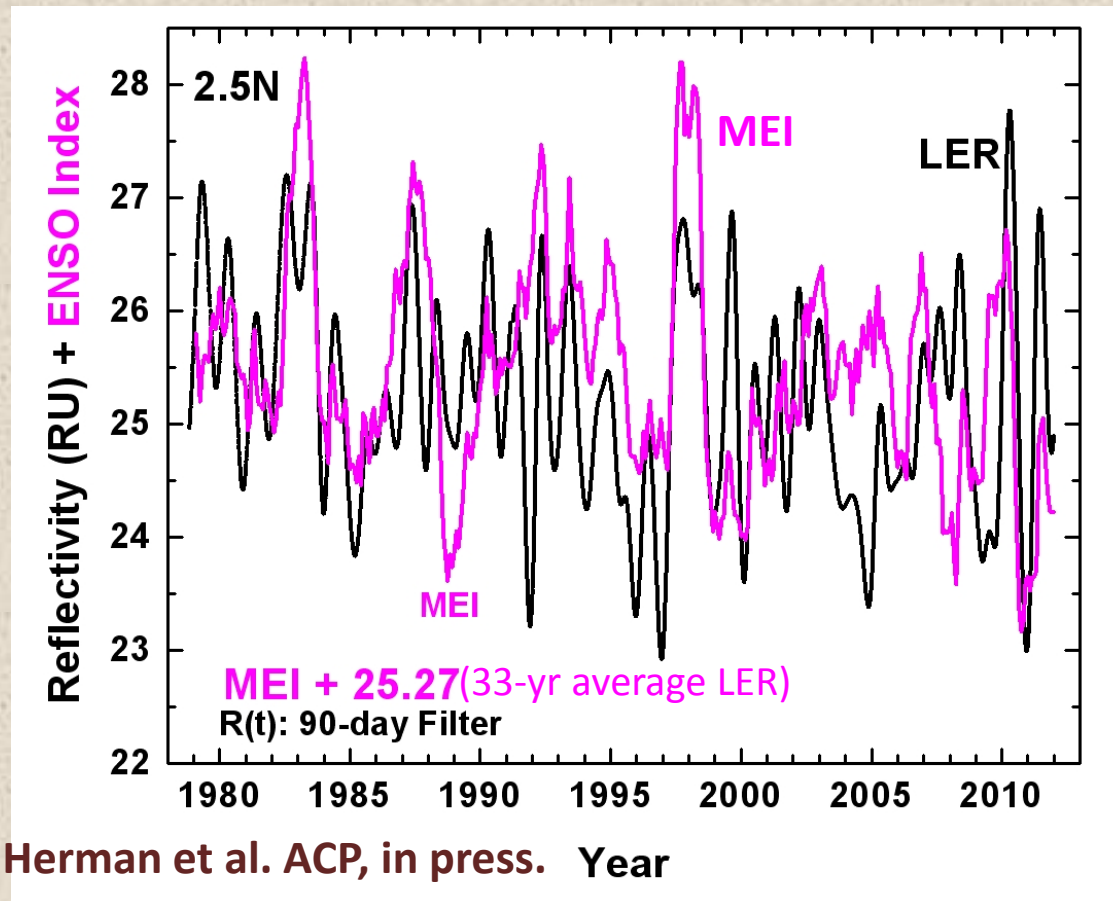
H_2O_v & O_3 are mostly anti-correlated. Clouds?

Data to Constrain Processes that Influence OH: *ENSO*



Initial Diagnostics/Datasets: ENSO-related

3) Clouds: SBUV, SBUV/2 - Lambert Equivalent Reflectivity (LER*)
(Jay Herman); MODIS - MOD08 product - ENSO (Andy Dessler); Jiang
et al. (2012) – CMIP5 analysis



MEI =
Multivariate
ENSO Index

LER =
combined
cloud,
aerosol, and
surface
reflectivities,
but clouds
cause most
change over
time

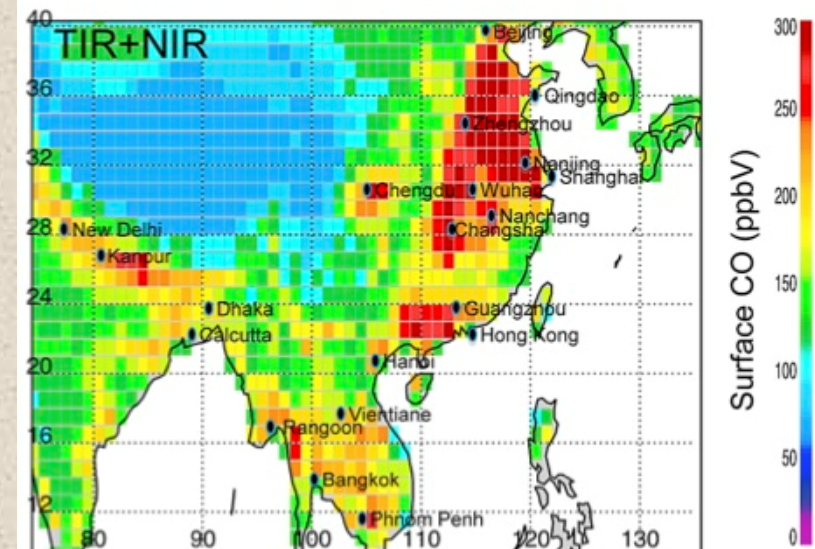
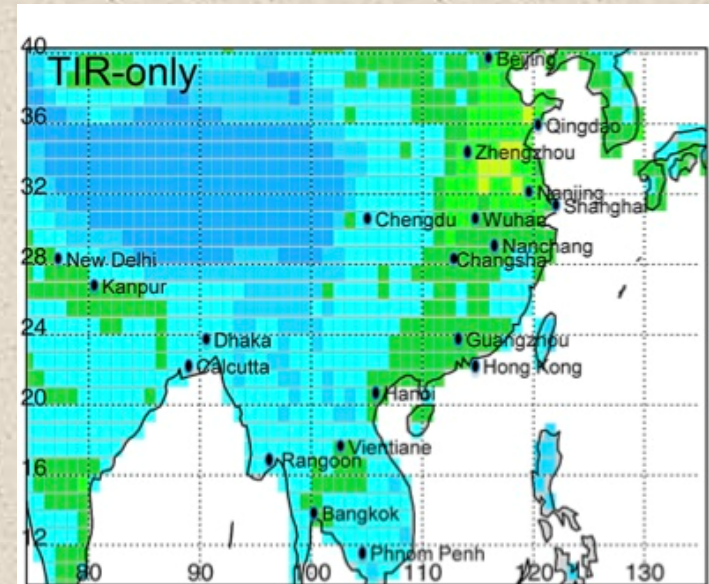
*LER (340 nm) has the advantage that it is not an ambiguous quantity like OD (which can saturate) and cloud fraction (which can be difficult to interpret).

MOPITT V5 & V6 CO

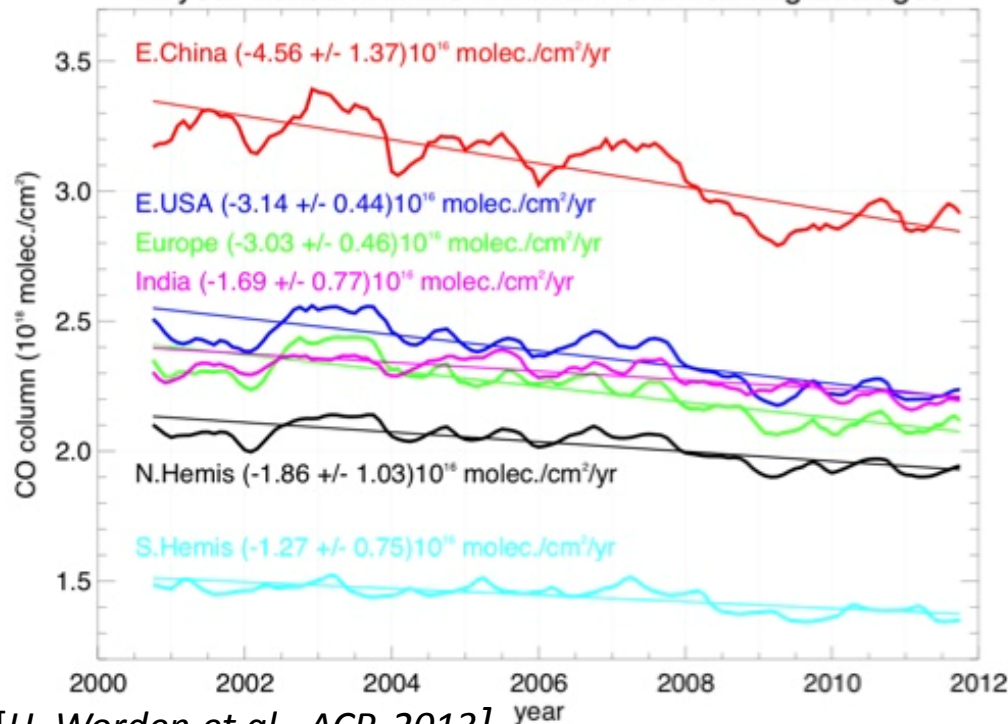
Joint retrieval with Thermal and Near IR (TIR+NIR) channels:

- greater sensitivity to surface
- increased vertical resolution

Surface CO Sept-Oct-Nov 2004-2008 average



11 year trends with MOPITT 12-month running averages



[H. Worden et al., ACP, 2013]

Deeter et al., JGR, 2009

H. Worden et al., JGR, 2010

Initial Diagnostics/Datasets – Model Output Required

*Unless specified, all output are monthly & 3d. T & P needed for most.
Good output to have: mass of air in gridbox, gridbox dimensions*

- 1) **Ozone**: atmospheric O_3 (1:30 pm local), U, V, W, & SSTs
- 2) **H₂O_v**: tropospheric H_2O (1:30 pm local)
- 3) **Clouds**: *Has the train left the station?*
- 4) **Overhead Ozone Column**: atmospheric O_3 , tropopause P (1:30 pm local)
- 5) **NO₂**: atmospheric NO_2 , tropopause P (1:30 pm local)
- 6) **CO**: tropospheric CO (10:30 am local)
- 7) **Methane**: tropospheric CH_4 , P_s , kg H_2O /kg air
- 8) **Lightning**: flash rates (35°N – 35°S)